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| FORM PTO-4390 (Modified) (REV 11-2000) | | U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE | | ATTORNEY'S DOCKET NUMBER 537-1070 | |
| TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371 | | | | U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 1.5) | |
| | | | | 10/088322 | |
| INTERNATIONAL APPLICATION NO. PCT/GB00/03534 | | INTERNATIONAL FILING DATE September 14, 2000 | | PRIORITY DATE CLAIMED September 16, 1999 | |
| TITLE OF INVENTION An Optical Interferometer Sensor Array | | | | | |
| APPLICANT(S) FOR DO/EO/US Paul Beard and Timothy Noel Mills | | | | | |
| Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information | | | | | |
| <ol style="list-style-type: none"> 1. <input checked="" type="checkbox"/> This is a FIRST submission of items concerning a filing under 35 U.S.C. 371 2. <input type="checkbox"/> This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371 3. <input type="checkbox"/> This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (24) indicated below 4. <input checked="" type="checkbox"/> The US has been elected by the expiration of 19 months from the priority date (Article 31). 5. <input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371 (c) (2)) <ol style="list-style-type: none"> a. <input type="checkbox"/> is attached hereto (required only if not communicated by the International Bureau) b. <input checked="" type="checkbox"/> has been communicated by the International Bureau. c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US) 6. <input type="checkbox"/> An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)) <ol style="list-style-type: none"> a. <input type="checkbox"/> is attached hereto b. <input type="checkbox"/> has been previously submitted under 35 U.S.C. 154(d)(4) 7. <input checked="" type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3)) <ol style="list-style-type: none"> a. <input type="checkbox"/> are attached hereto (required only if not communicated by the International Bureau) b. <input type="checkbox"/> have been communicated by the International Bureau c. <input type="checkbox"/> have not been made, however, the time limit for making such amendments has NOT expired d. <input checked="" type="checkbox"/> have not been made and will not be made 8. <input type="checkbox"/> An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)) 9. <input type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)). 10. <input type="checkbox"/> An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)) 11. <input type="checkbox"/> A copy of the International Preliminary Examination Report (PCT/IPEA/409) 12. <input type="checkbox"/> A copy of the International Search Report (PCT/ISA/210) <p>Items 13 to 20 below concern document(s) or information included:</p> <ol style="list-style-type: none"> 13. <input type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98 14. <input type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included 15. <input checked="" type="checkbox"/> A FIRST preliminary amendment 16. <input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment 17. <input type="checkbox"/> A substitute specification 18. <input type="checkbox"/> A change of power of attorney and/or address letter 19. <input type="checkbox"/> A computer-readable form of the sequence listing in accordance with PCT Rule 13ter 2 and 35 U.S.C. 1.821 - 1.825 20. <input type="checkbox"/> A second copy of the published international application under 35 U.S.C. 154(d)(4) 21. <input type="checkbox"/> A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4) 22. <input type="checkbox"/> Certificate of Mailing by Express Mail 23. <input type="checkbox"/> Other items or information | | | | | |

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| U.S. APPLICATION NO (IF KNOWN, SEE 37 CFR 1.5) <div style="font-size: 1.5em; font-weight: bold;">10/088322</div> | | INTERNATIONAL APPLICATION NO PCT/GB00/03534 | | ATTORNEY'S DOCKET NUMBER 537-1070 | |
|---|--|---|--|---|--|

24. The following fees are submitted:

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

| | |
|--|------------------|
| <input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO | \$1040.00 |
| <input checked="" type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO | \$890.00 |
| <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO | \$740.00 |
| <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) | \$710.00 |
| <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) | \$100.00 |

ENTER APPROPRIATE BASIC FEE AMOUNT =

Surcharge of **\$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e))

| CLAIMS | NUMBER FILED | NUMBER EXTRA | RATE | FEE | TOTAL |
|---|--------------|--------------|-----------|--------|---------------------------|
| Total claims | 17 - 20 = | 0 | x \$18 00 | \$0.00 | \$0.00 |
| Independent claims | 1 - 3 = | 0 | x \$84 00 | \$0.00 | \$0.00 |
| Multiple Dependent Claims (check if applicable) <input type="checkbox"/> | | | | | \$0.00 |
| TOTAL OF ABOVE CALCULATIONS = | | | | | \$890.00 |
| <input checked="" type="checkbox"/> Applicant claims small entity status See 37 CFR 1.27) The fees indicated above are reduced by 1/2 | | | | | \$445.00 |
| SUBTOTAL = | | | | | \$445.00 |
| Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (f)) | | | | | \$0.00 |
| TOTAL NATIONAL FEE = | | | | | \$445.00 |
| Fee for recording the enclosed assignment (37 CFR 1.21(h)) The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). <input type="checkbox"/> | | | | | \$0.00 |
| TOTAL FEES ENCLOSED = | | | | | \$445.00 |
| | | | | | Amount to be: refunded \$ |
| | | | | | charged \$ |

CALCULATIONS PTO USE ONLY

a. ☒ A check in the amount of **\$445.00** to cover the above fees is enclosed

b. ☐ Please charge my Deposit Account No _____ in the amount of _____ to cover the above fees. A duplicate copy of this sheet is enclosed

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No **12-0913** A duplicate copy of this sheet is enclosed

d. ☐ Fees are to be charged to a credit card **WARNING:** Information on this form may become public **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO

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SIGNATURE

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26,935

REGISTRATION NUMBER

March 14, 2002

DATE

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 NAME

 REGISTRATION NUMBER

 DATE

10088322/088322

IC10 Rec'd PCT/PTO 14 MAR 2002

537-1070

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

IN RE THE APPLICATION OF)
Paul Beard et al) Examiner:
SERIAL NO.: To Be Assigned) Group Art Unit:
FILED: Herewith)
FOR: AN OPTICAL INTERFEROMETER)
SENSOR ARRAY)

AMENDMENT ACCOMPANYING APPLICATION

Honorable Director of Patents
and Trademarks
Washington, D.C. 20231

Dear Sir:

The present application is the national filing of international application number PCT/GB00/03534. Before calculation of the filing fee for the United States, it requested that the application be amended as follows:

IN THE CLAIMS:

Amend claims 4, 6 - 9, 11 - 14, 16 and 17 as follows:

4. (Amended) An interferometer as claimed in claim 1, wherein the polymer film has a thickness greater than 5 μ m.

6. (Amended) An interferometer as claimed in claim 1, wherein the polymer film has a Young's modulus less than 15 Gpa.

7. (Amended) An interferometer as claimed in claim 1, wherein the polymer film comprises a single layer polymer structure deposited directly onto the substrate.
8. (Amended) An interferometer as claimed in claim 1, wherein the interrogation signal source comprises a continuous wave interrogating laser source.
9. (Amended) An interferometer as claimed in claim 1, further comprising an excitation source arranged to provide an excitation signal to a sample for analysis through the sensor head.
11. (Amended) An interferometer as claimed in claim 1, further comprising an optical expanding beam arrangement disposed between the sensor head and the optical sensing device.
12. (Amended) An interferometer as claimed in claim 1, further comprising an optically diverging lens arrangement disposed between the interrogation signal source and the sensor head, for altering the degree of collimation of the interrogation signal provided to the sensor head.
13. (Amended) An interferometer as claimed in [any preceding] claim 1, further comprising means for measuring the surface temperature at the sensor head.
14. (Amended) An interferometer as claimed in [any preceding] claim 1, further comprising an optical arrangement for altering the angle of incidence of the interrogation signal on the sensor head.
16. (Amended) A method of manufacturing an interferometer according to claim 1, comprising the step of, on a transparent substrate, forming a polymer sensing film by spin coating

a liquid polymer on the substrate.

17. (Amended) A method of manufacturing an interferometer according to claim 1, comprising of the steps of;

thermally evaporating a polymer onto the surface of a transparent substrate;

condensing the polymer into a liquid phase; and

curing the liquid phase polymer using a radiation source thereby forming a solid polymer film on the substrate.

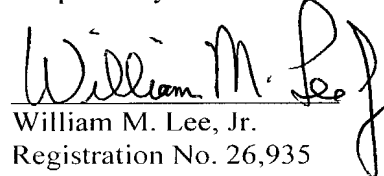
Remarks

The above amendments are being made in order to eliminate multiple dependency and improper multiple dependency from the application before calculation of the application filing fee. Should any multiple dependency remain, that is unintended, and the Patent and Trademark Office is requested to cancel any remaining multiple dependent claims without prejudice before calculation of the application filing fee.

Examination of the application on its merits is awaited.

Dated: March 14, 2002

Respectfully submitted,



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Version With Markings To Show Changes Made**CLAIMS:**

4. (Amended) An interferometer as claimed in [any preceding] claim 1, wherein the polymer film has a thickness greater than 5 μ m.
6. (Amended) An interferometer as claimed in [any preceding] claim 1, wherein the polymer film has a Young's modulus less than 15 Gpa.
7. (Amended) An interferometer as claimed in [any preceding] claim 1, wherein the polymer film comprises a single layer polymer structure deposited directly onto the substrate.
8. (Amended) An interferometer as claimed in [any preceding] claim 1, wherein the interrogation signal source comprises a continuous wave interrogating laser source.
9. (Amended) An interferometer as claimed in [any preceding] claim 1, further comprising an excitation source arranged to provide an excitation signal to a sample for analysis through the sensor head.
11. (Amended) An interferometer as claimed in [any preceding] claim 1, further comprising an optical expanding beam arrangement disposed between the sensor head and the optical sensing device.

12. (Amended) An interferometer as claimed in [any preceding] claim 1, further comprising an optically diverging lens arrangement disposed between the interrogation signal source and the sensor head, for altering the degree of collimation of the interrogation signal provided to the sensor head.
13. (Amended) An interferometer as claimed in [any preceding] claim 1, further comprising means for measuring the surface temperature at the sensor head.
14. (Amended) An interferometer as claimed in [any preceding] claim 1, further comprising an optical arrangement for altering the angle of incidence of the interrogation signal on the sensor head.
16. (Amended) A method of manufacturing an interferometer according to [any preceding] claim 1, comprising the step of, on a transparent substrate, forming a polymer sensing film by spin coating a liquid polymer on the substrate.
17. (Amended) A method of manufacturing an interferometer according to [any of claims 1 to 15] claim 1, comprising of the steps of;
- thermally evaporating a polymer onto the surface of a transparent substrate;
 - condensing the polymer into a liquid phase; and
 - curing the liquid phase polymer using a radiation source thereby forming a solid polymer film on the substrate.

An Optical Interferometer Sensor Array

This invention relates to an interferometer sensor, and in particular to an interferometer sensor
5 for detecting an incident acoustic signal pattern over a two-dimensional area, particularly but not
exclusively for bio-medical ultrasonic sensing applications.

Time-resolved photoacoustic techniques are well known, which involve the excitation of a
sample using sub-ablation threshold laser excitation pulses, the excitation of the sample resulting
10 in the production of ultrasonic thermoelastic waves. The amplitude and temporal characteristics
of these waves depend upon the optical, thermal, acoustic and other physical properties of the
sample and can be used to provide information relating to its composition and structure.

Various methods have been proposed to enable the analysis of these ultrasonic thermoelastic
15 waves, each using ultrasound detectors arranged on the surface of the sample under analysis. For
example, tomographic imaging involves the use of detectors arranged around the periphery of the
sample, and a reconstruction algorithm enables a slice image to be generated. To produce a three
dimensional image of the sample, a large number of slice images must be obtained. This either
requires a large number of discrete detectors positioned over the entire surface of the object, or
20 else repositioning of sensors between each slice image acquisition. Furthermore, the processing
required to reconstruct the final three-dimensional image is complex.

Alternatively, a two-dimensional sensor can be employed which spatially resolves the acoustic
signal at each point across the surface of the sample, to obtain a volume image.

25 Line-of-sight sensors rely on the assumption that photoacoustic signals detected at individual
sensor elements originate only from sample material along the "line-of-sight" of the sensor
element. Of course, if useful penetration depths are required, highly directional sensor elements
are required having large aperture, and therefore the lateral resolution is poor. The lateral
30 dimensions of the image are limited to the footprint of the sensor being used as a result of the
highly directional sensor elements.

Phased-array sensors rely on small omnidirectional sensor elements and apply synthetic focusing techniques to the image data set to interrogate each point in the irradiated volume. This type of "beam-steering" approach enables signals to be received from subsurface objects that are situated outside the footprint of the sensor.

One difficulty in implementing these methods for bio-medical acoustic imaging applications is the requirement for a high resolution two-dimensional array of acoustic sensors. Conventional sensor elements comprise piezoelectric pressure sensing elements. Difficulties arise in obtaining the required small element size and pitch for unambiguous high-resolution beam-steering with sufficient detection sensitivity.

The article "Optical multilayer detection array for fast ultrasonic field mapping" by V. Wilkens and Ch. Kock in Optics Letters Vol 24, No. 15, 1st August 1999 describes a detection array in which an acoustic signal is detected over a two dimensional area of the surface of the sample under analysis using interferometer principles. The pressure signals appearing at the surface of the sample are converted to optical signals for detection by a remote photodetector or photodetector array. This conversion is performed by an interferometer device comprising a 19 layer dielectric structure deposited over a substrate, to which an interrogation signal is applied. This dielectric structure operates as a pair of mirror surfaces with a small spacing between them. The dielectric layers are relatively hard, having Young's modulus in the range 70 to 100 GPa, and so give poor sensitivity to the incident acoustic signal. To compensate for this, the dielectric structure is arranged to enable the device to operate in a high finesse mode of operation for a relatively narrow bandwidth of signals for detection.

According to a first aspect of the present invention there is provided an interferometer sensor comprising: a two dimensional sensor head comprising a polymer film of substantially uniform thickness disposed over a substrate; an optical interrogation signal source for providing an interrogating signal to the sensor head, the interrogation signal extending across the area of the sensor head and being incident normally to the sensor head, the sensor head providing an optical output signal over the area of the sensor head in dependence on incident signals detected by the

sensor; and an optical sensing device arranged to receive the optical output signal from the sensor head at a location remote from the sensor head.

The sensor of the invention converts ultrasound signals appearing over a two dimensional surface to an optical signal pattern, using a polymer interferometer sensing film. Localised variations in the thickness of the sensing film caused by the ultrasound signal pattern being measured modulate the outputs of the sensor head. Spatial discretisation of the ultrasound signal pattern is performed by an optical sensing device. Such optical devices can be arranged having sufficiently high resolution to enable beam-steering imaging to be performed, including imaging outside the footprint of the sensor head. The use of a polymer film interferometer sensor gives rise to high sensitivity and can enable a low finesse mode of operation to be sufficient for image acquisition and processing. Low finesse operation gives improved bandwidth and linearity of response.

Preferably, the optical sensing device comprises a two-dimensional photodetector array. In an alternative example, the photodetecting element comprises a photodiode or photodiode array of smaller size than the area of the sensor head, arranged to scan the output from the sensor head across its area.

The polymer film preferably has a thickness greater than $5\mu\text{m}$. The thickness is selected to be as large as possible to improve sensitivity, but with the constraint that the thickness should remain below the wavelength of the signal to be detected. For example acoustic signals of 20MHz in water have an approximate wavelength of $70\mu\text{m}$ (taking the speed of sound in fresh water to be 1410m/s). Accordingly, the polymer sensing film may have a thickness in the range $30\mu\text{m}$ to $60\mu\text{m}$.

The polymer film preferably has a Young's modulus less than 15 GPa, to improve the sensitivity of the film to the incident acoustic signal. The polymer film preferably comprises a single layer polymer structure deposited directly onto the substrate.

The interrogation signal source may comprise a continuous wave interrogating laser source. An excitation source may also be provided to supply an excitation signal, for example laser

sensor head 1. One of the beamsplitters reflects a sample investigation signal from a signal source to the sensor head, and this signal passes through the head 1 into the sample.

5 The sample investigation signal may comprise laser excitation pulses for irradiating a volume of the sample, to excite the sample to produce ultrasonic thermoelastic waves for detection. In this case, the signal source comprises a pulsed laser source, and the beamsplitter 6 may then comprise a dichroic mirror which reflects the excitation wavelength but which transmits at the wavelength of the interrogation signal (discussed below).

10 Alternatively, the input signal may comprise an ultrasound signal for ultrasound imaging based on the detection of acoustic echoes at subsurface features where there is an acoustic mismatch. In this case, the signal source may comprise a piezoelectric transducer, and the beamsplitter 6 may then comprise a glass plate which acts as a good acoustic reflector in water and is transparent to the interrogation signal (discussed below). The ultrasound source is then be
15 coupled acoustically to the sensor by having the signal source, beamsplitter 6 and sensor head in water.

The other beamsplitter 8 reflects an interrogation signal from an interrogation signal source to the sensor head 1. A two-dimensional optical sensing device, in the form of a photodiode array
20 16, is provided at a location remote from the sensor head 1 and receives phase modulated reflected interrogation signals from the sensor head 1. As explained above, since the location of the photodetector array is remote from the sensor head, the spatial discretisation of the acoustic signal is implemented optically at this remote location.

25 The sensor head comprises a polymer film 2 deposited on to the optically transparent substrate 4 having matched acoustic impedance to minimise acoustic reflections. The acoustic impedance of the polymer layer can also be selected to match the medium in which the sensor is to operate, normally water. The thickness of the film 2 is selected to be as large as possible to improve sensitivity, but with the constraint that the thickness should remain below the wavelength of the
30 signal to be detected. In biomedical photoacoustic imaging techniques, signal frequencies of around 30MHz are to be detected, having an approximate wavelength of 47µm. The film

thickness should be less than the wavelength of the signal to be detected to achieve sufficient acoustic bandwidth. Thus, the film thickness may be of the order of 40 μ m, although the thickness can be selected according to the specific application. The polymer film preferably has a Young's modulus less than 15 GPa, to improve the sensitivity of the film to the incident acoustic signal, and it comprises a single layer polymer structure deposited directly onto the substrate.

In use of the example represented in Figure 1, which provides laser excitation of the sample, nanosecond excitation laser pulses from a wavelength tuneable source (not shown) are transmitted through the sensor head 1 to the sample 14. The structure of the sensor head is designed to be transparent to the excitation pulses to enable these to pass into the sample. The sensor head 1 is illuminated by the output of a tuneable continuous wave interrogating laser source (not shown) which is arranged to provide interrogation signals 12 to the sample. The polymer sensing film 2 acts as a two-dimensional Fabry Perot interferometer, the mirrors of which are formed at the opposing sides of the polymer film.

The reflections may be obtained simply as a result of the refractive index mismatch at the two sides of the film. Wavelength-selective dielectric reflective coatings or films may be deposited during manufacture of the sensor head 1, designed to be reflective at the wavelength of the continuous wave interrogation signal but transparent to the excitation laser pulses 10 provided by the laser excitation source (not shown), thereby ensuring that the excitation pulses penetrate the sensor head.

The excitation laser pulses cause the generation of photoacoustic waves from each point in the irradiated volume of the sample 14, which are then incident on the polymer sensing film 2. The sample is diffusely irradiated if it is optically scattering, which is the case for biological soft tissue. The incident photoacoustic waves modulate the optical thickness of the polymer sensing film, thereby modulating the reflected interrogation light signals 12. The reflected interrogation light is then directed onto the two-dimensional photodiode array 16 providing a representation of the incident acoustic field across the sensing film 2. In its simplest form, there is a one-to-one mapping so that the effective acoustic element size and spacing corresponds to the optical pixel

size and spacing of the optical photodiode array.

The output of the photodiode array 16 is coupled to processor 18 where it is processed to provide a three-dimensional image of the sample 14 being studied, in the same way that the output of a piezoelectric ultrasound detecting array is processed to implement line-of-sight or phased array processing.

To perform line-of-sight imaging, the output of groups of the photodiodes in the array 16 are summed to synthesise an array of directional detector elements that receive photoacoustic signals only along their line-of-sight. For example, photodiode elements having 100µm pitch may be grouped together to form highly directional elements with an effective diameter of 1mm.

Phased array processing can also be performed by applying suitable time delays to each element individually to synthetically adjust the receive focus of the array 16. By steering the synthetic receive focus of the phased array through the irradiated volume of the sample 14, a three-dimensional image of the sample 14 can be constructed from a detected data set from a single shot laser excitation pulse. Furthermore, using phased array beam-steering methods, it is possible to obtain an image of the sample outside the footprint of the sensor head.

The phased array approach requires each element to be omnidirectional, and therefore the effective diameter of each element must be small in comparison to the acoustic wavelength. Input signals entering the sensor at an angle to the longitudinal axis will be integrated over the effective area of the sensor, and as a result a smaller effective area improves the directional response of the sensor. Sensor element sizes of a few tens of microns may be desired, which, for one-to-one mapping of the acoustic signal to the photodiode array, requires the pixel diameter of the photodiode pixels of the array to have corresponding size. This may increase the cost of the optical sensor or render it impractical.

To overcome this problem, an optical expanding beam arrangement may be disposed between the sensor head 1 and the array 16, particularly between the beamsplitter 8 and the array 16. As represented in Figure 2, the expanding beam arrangement may comprise a diverging lens 20 and

a converging lens 22 in series. The diverging lens 20 is provided in the path of the light from the beamsplitter 8, and the converging lens is provided closer to the array 16. The focal lengths f_{20} , f_{22} of the two lenses are selected so that the focal points coincide, as shown. This ensures that normally incident beams remain normal at the output of the diverging arrangement. The mapping is then no longer one-to-one and the effective acoustic element size and spacing can be reduced. There is a limit to the smallest area of the polymer film that can be addressed due to acoustic cross coupling effects, but it has been found that effective areas of less than $50\mu\text{m}$ can be achieved.

The wavelength of the excitation pulses can be selected to obtain desired depth, range and contrast characteristics for the specific application of the sensor. For example, near infra-red wavelengths may penetrate deeply into a sample, whereas improved resolution may be obtained at lower depths with different excitation pulses. The maximum depth at which photoacoustic signals can be detected is an important parameter for the practical use of the sensor in biomedical imaging.

The sensor may operate as a low finesse Fabry-Perot interferometer, and the low Young's modulus gives rise to sufficient sensitivity of the sensor. High finesse operation can also be achieved through the use of low absorption high reflectivity dielectric coatings, which are transmissive at the excitation wavelength. The dynamic range suffers when high finesse operation is achieved, but to increase the upper detection limit the degree of collimation of the interrogation signal can be reduced to increase phase dispersion within the interferometer and reduce the finesse.

This slight reduction in finesse can be achieved by increasing the divergence of the interrogating beam incident on the sensor head. An optically diverging lens arrangement may be provided for this purpose between the beamsplitter 6 and the sensor head 4, as shown in Figure 3. This arrangement may comprise a diverging lens 24 and a converging lens 26 in series. The diverging lens 24 is provided in the path of the interrogation signal from the beamsplitter 6, and the converging lens is provided closer to the sensor head 1. The focal lengths f_{24} , f_{26} and separation of the two lenses are selected so that normally incident beams are caused to diverge. The degree

of collimation can then be adjusted by varying the spacing between the two lenses.

The sensor of the invention may be used as a hand held imaging head for use in, amongst other applications, breast cancer detection. In such a device, optical fibre transportation of the
5 interrogation and reflected signals may be employed.

The device may also be used for photo thermal imaging. In addition to detecting ultrasonic photoacoustic signals generated throughout the irradiated volume, the decay of the surface temperature distribution immediately following the absorption of the laser pulse could be
10 detected. This can provide information on the optical and thermal properties of the target. A possible application would be to study the photo thermal response of skin to diagnose abnormalities such as malignant melanoma.

The Fabry Perot sensing film must have good optical and physical properties to enable detection
15 with high signal to noise ratio of the modulation of the sensor film thickness caused by the incident photoacoustic signals. Two possible examples of methods of manufacturing the polymer sensor film described below are spin-coating and polymer deposition from a gas phase via a liquid phase.

20 To form the polymer sensing film by spin coating, a liquid polymer such as polymethyl methacrylate (PMMA), polystyrene or polyimide, is poured onto a substrate, the substrate then being rotated on a turntable. The liquid polymer is generally obtained by dissolving in an appropriate solvent, which evaporates to leave the polymer. The centripetal forces experienced by the liquid polymer cause it to spread over a central region of the substrate thereby forming the
25 sensor film.

To form the polymer sensing film by polymer deposition from a gas-phase (via a liquid-phase), a bulk sample of the polymer to be used is heated and thermally evaporated onto the substrate using, for example, an electric heater. The vapour then condenses to a liquid on the substrate and
30 is cured using ultra-violet light or an electron beam. This method produces large area Fabry Perot sensing films having good uniformity, which are therefore particularly suitable for bio-

medical applications.

PMMA or PTFE are examples of suitable polymers for the formation of the film by thermal evaporation.

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Other possible processes for forming the polymer film are sputtering or the parylene polymerisation process.

Even with highly uniform conformal polymer coatings, the optical thickness of the interferometer will vary across the illuminated region of the polymer sensing film. These variations may, for example, be of the order of hundreds of nanometres. These may be large enough to produce significant variations in phase bias and hence sensitivity across the film.

It may therefore be necessary to adjust or control the phase bias so that each point across the sensing area can be interrogated with maximum sensitivity.

The phase bias ϕ is given by:

$$\phi = \frac{4\pi nl}{\lambda} \cos \theta$$

20

where n is the refractive index of the polymer film, l the thickness, λ the light source wavelength and θ is the angle of incidence.

One approach for controlling the phase bias is to vary the interrogation signal wavelength for different points on the film, for example by using a tuneable laser source. A computer controlled tuneable external cavity laser diode and a mechanically scanned photodiode can be used to obtain a map of the reflected fringes over the surface of the sensor to evaluate the variation in optical thickness. The interrogation requirements in terms of speed and wavelength can then be determined for each point on the array.

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11

An alternative is to vary θ which is referred to as angle tuning. Figure 4 shows one possible implementation of an angle tuning system. Changing the angle θ_i of the input beam from the laser source 28 using an angle tuning element 30 produces a corresponding change in the angle θ_o of the light incident on the sensor without translation across its surface. This is achieved by means of the lenses 32,34 which are spaced by twice their focal lengths, f . The reflected signal from the polymer film 4 is directed by the beam splitter 36 on to the photodiode array 16. The beam splitter 36 is positioned at the focal points of the two lenses 32,34, and directs the signal to the array 16 through a focusing lens 38. This lens and splitter arrangement is configured such that the light reflected from the sensor 1 is imaged on to the photodiode array 16 also without translation as θ is varied.

Using this system, the reflected interference fringes, the spatial derivatives of which can be thought of as contours of uniform sensitivity, can be scanned across the illuminated area of the polymer sensor film enabling each point to be interrogated with optimum sensitivity. The three lenses 32, 34, 38 are of the same focal lengths f and aperture which gives a linear magnification (ratio of output to input beam diameters) and angular tuning gain (θ_o / θ_i) of unity. If required, various other combinations of lenses could be chosen to increase θ_o / θ_i and alter the output beam diameter. The angle tuning element 30 could be an electromechanical device such as a moving coil or moving magnet optical scanning mirror, a rotating polygon mirror or an electro-optic device such as a Bragg cell.

There are various control schemes which enable near-uniform optimum sensitivity to be obtained at each point across the sensing region, namely the area of the illuminating beam.

A closed loop scheme can be employed whereby the output of a single element of the detector array is monitored as θ_o is varied over a sufficiently large range that a phase shift of at least π radians is produced. The transfer function of the interferometer is thus obtained for that point. The angle that corresponds to the phase bias that results in the maximum sensitivity (i.e. when the phase derivative of the interferometer transfer function is at maximum) is identified and is then used to bias the interferometer. A measurement of the signal is taken and the process repeated in turn for each element of the optical detector array. This approach requires the signal

to be detected to be repetitive. To obtain the interferometer transfer function derivative directly and in real time, a small dither angle modulation could be superimposed and continuously monitored.

5 A continuous scanning approach, by which the sensor is scanned with all angles for each measurement, also assumes that the signal to be detected is repetitive. θ_0 is varied continuously with a sinusoidal or a sawtooth waveform at frequency f_r . Providing the resulting interferometer phase bias excursion is at least π radians, all points across the sensing area would at some time within the scan period ($1/f_r$) experience the optimum phase bias corresponding to the maximum
10 sensitivity. Providing the signal repetition rate f_r of the signal to be detected is substantially greater than f_r , a signal from any detector element will be detected with optimum sensitivity at least once within the scan period. In practice, the signal would be extracted using envelope detection methods or averaging the absolute amplitude of all the signals obtained over a π phase bias excursion. Additionally, it would be useful to apply a small dither angle modulation at
15 a frequency f_m such that $f_s \gg f_m \gg f_r$ where f_s is the minimum frequency component of the signal. By subjecting the sensor output at the dither frequency to the same processing (averaging or envelope detection) as the signal, variations in interferometer sensitivity across the sensing region, perhaps due to non uniformities in the spatial distribution of the illuminating beam or imperfections in the polymer film or reflective coatings, could be obtained in real time.

20 In an amplitude modulation scheme, the phase bias is modulated through π radians at a frequency f_r substantially greater than the maximum frequency component of the signal. The output of each detector element is therefore an amplitude modulated carrier which can then be demodulated using conventional AM demodulation techniques. The signal does not need to be repetitive as the
25 interferometer transfer function is effectively sampled many times over the duration of the signal at each point across the sensing region. Since the frequency content of the signal can extend to several tens of MHz if detecting ultrasound fields, the angle tuning element 30 would have to be an electro-optic rather than electromechanical device.

30 Various modifications will be apparent to those skilled in the art.

CLAIMS

1. An interferometer sensor comprising:
a two-dimensional sensor head comprising a polymer film of substantially uniform
5 thickness disposed over a substrate;
an interrogation signal source for providing an interrogating signal to the sensor head, the
interrogation signal extending across the area of the sensor head and being incident normally to
the sensor head, the sensor head providing an optical output signal over the area of the sensor
head in dependence on incident signals detected by the sensor; and
10 an optical sensing device arranged to receive the optical output signal from the sensor
head at a location remote from the sensor head.
2. An interferometer according to claim 1, in which the optical sensing device comprises a
two-dimensional photodetector array.
- 15 3. An interferometer according to claim 1, in which the optical sensing device comprises a
photodiode arranged to scan the output from the sensor head across its area.
4. An interferometer as claimed in any preceding claim, wherein the polymer film has a
20 thickness greater than 5µm.
5. An interferometer as claimed in claim 4, in which the polymer sensing film has a
thickness in the range 30µm to 60µm.
- 25 6. An interferometer as claimed in any preceding claim, wherein the polymer film has a
Young's modulus less than 15 GPa.
7. An interferometer as claimed in any preceding claim, wherein the polymer film
comprises a single layer polymer structure deposited directly onto the substrate.
- 30 8. An interferometer as claimed in any preceding claim, wherein the interrogation signal

source comprises a continuous wave interrogating laser source.

9. An interferometer as claimed in any preceding claim, further comprising an excitation source arranged to provide an excitation signal to a sample for analysis through the sensor head.

10. An interferometer according to claim 9, in which the excitation source comprises a laser light source arranged to provide excitation pulses to the sensor head.

11. An interferometer as claimed in any preceding claim, further comprising an optical expanding beam arrangement disposed between the sensor head and the optical sensing device.

12. An interferometer as claimed in any preceding claim, further comprising an optically diverging lens arrangement disposed between the interrogation signal source and the sensor head, for altering the degree of collimation of the interrogation signal provided to the sensor head.

13. An interferometer as claimed in any preceding claim, further comprising means for measuring the surface temperature at the sensor head.

14. An interferometer as claimed in any preceding claim, further comprising an optical arrangement for altering the angle of incidence of the interrogation signal on the sensor head.

15. An interferometer as claimed in claim 14, wherein different angles of incidence are selected for different locations of the sensor head.

16. A method of manufacturing an interferometer according to any preceding claim, comprising the step of, on a transparent substrate, forming a polymer sensing film by spin coating a liquid polymer on the substrate.

17. A method of manufacturing an interferometer according to any of claims 1 to 15, comprising the steps of;

thermally evaporating a polymer onto the surface of a transparent substrate;

condensing the polymer into a liquid phase; and
curing the liquid phase polymer using a radiation source thereby forming a solid polymer
film on the substrate.

5 18. A method according to claim 17, in which the radiation source comprises an ultra-violet
radiation source.

19. A method according to claim 17, in which the radiation source comprises an electron
beam.

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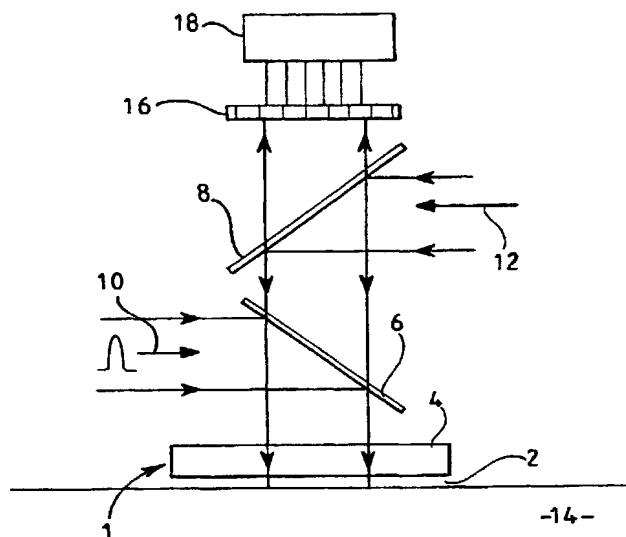
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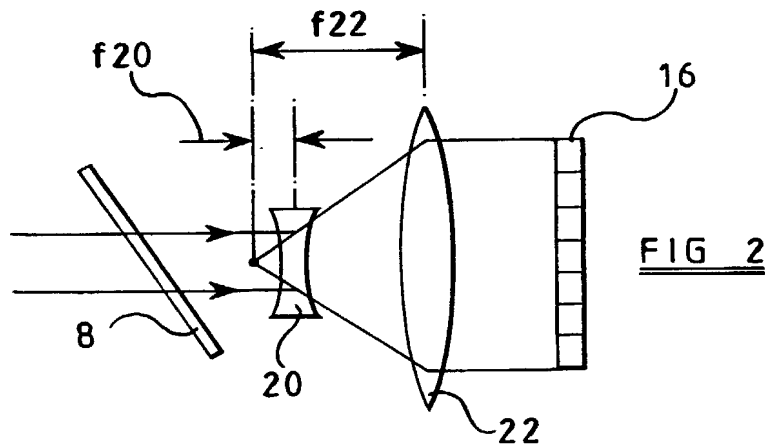
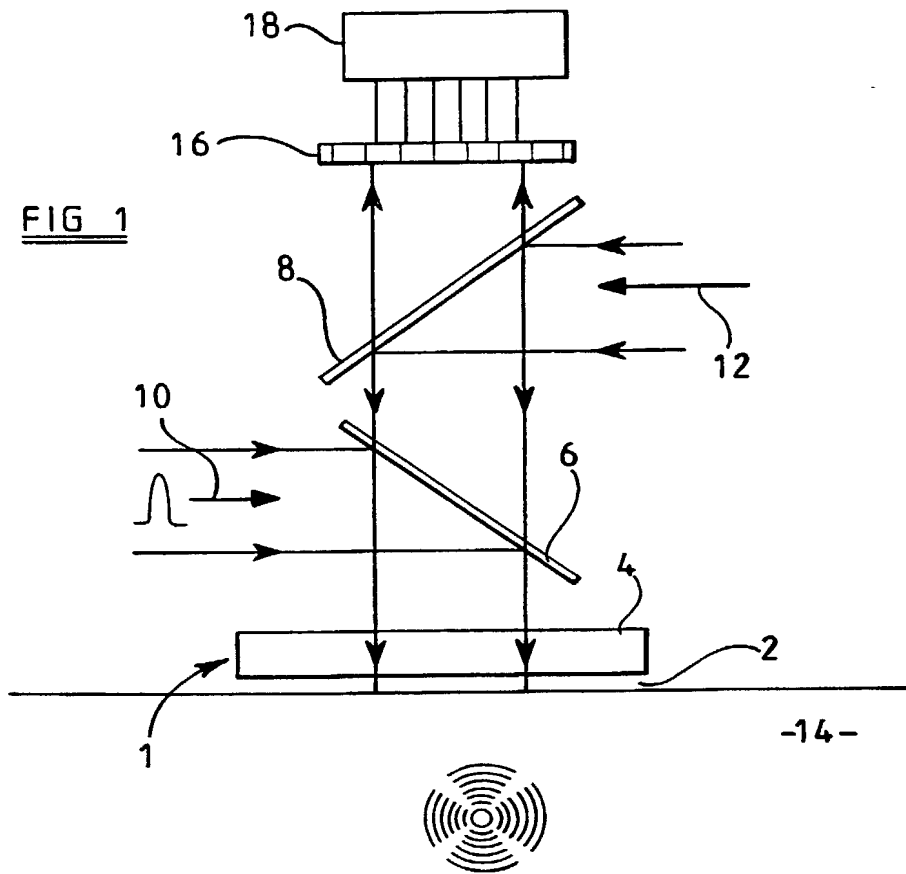


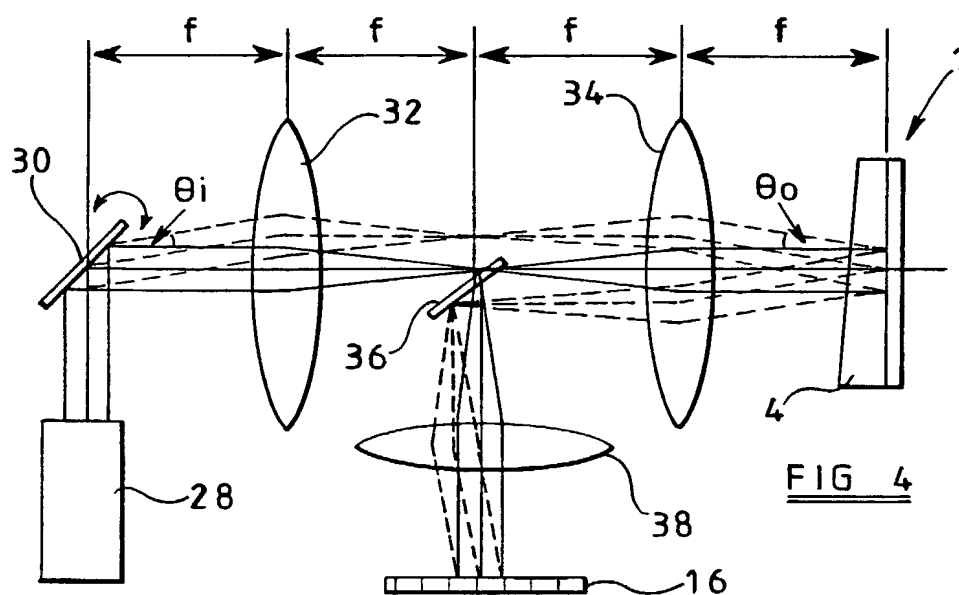
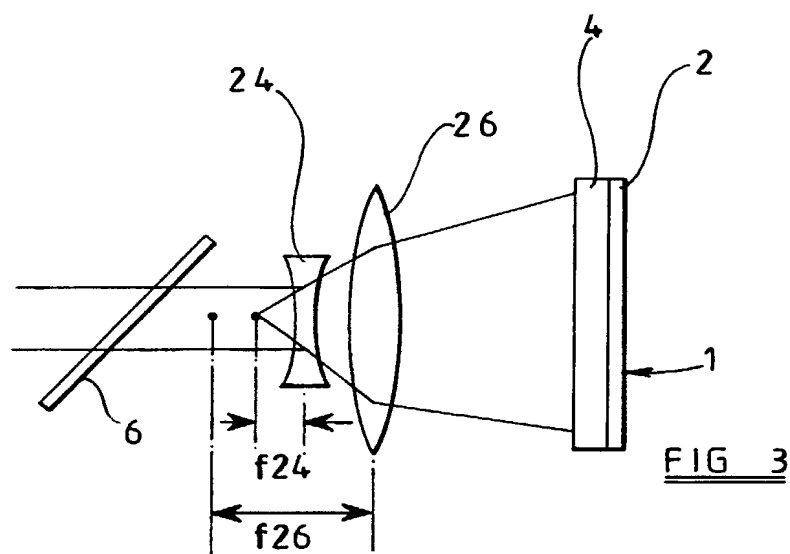
(57) Abstract: An interferometer sensor has a two-dimensional sensor head (1) comprising a polymer film (4) of substantially uniform thickness. An interrogating signal (12) is provided to the sensor head, the interrogation signal extending across the area of the sensor head and being incident normally to the sensor head (1). An optical sensing device (16) is arranged to receive an optical output signal from the sensor head at a location remote from the sensor head. The sensor converts ultrasound signals appearing over a two dimensional surface to an optical signal pattern, using a polymer interferometer sensing film. Spatial discretisation of the ultrasound signal pattern is performed by an optical sensing device. Such optical devices can be arranged having sufficiently high resolution to enable beam-steering imaging to be performed, including imaging outside the footprint of the sensor head.

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FIG 1

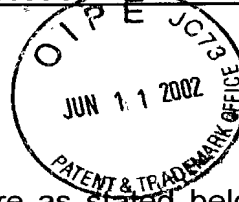




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DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:



My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **AN OPTICAL INTERFEROMETER SENSOR ARRAY**, the specification of which:

- ☐ is attached hereto.
- ☒ was filed on **14 March 2002** as

Application Serial No. _____

and was amended on **14 March 2002** if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate

having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

Priority Claimed

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|----------------|------------------|--------------------------|-------------------------------------|--------------------------|
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| | | | <input type="checkbox"/> | <input type="checkbox"/> |

I hereby claim the benefit under Title 35, United States Code Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

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And I hereby appoint Thomas E. Smith, Registration No. 18,243, Dennis M. McWilliams, Registration No. 25,195, James R. Sweeney, Registration No. 18,721, William M. Lee, Jr., Registration No. 26,935, Glenn W. Ohlson, Registration No. 28,455, David C. Brezina, Registration No. 34,128, Jeffrey R. Gray, Registration No. 33,391, Timothy J. Engling, Registration No. 39,970, Gregory B. Beggs, Registration No. 19,286, Gerald S. Geren, Registration No. 24,528, Peter J. Shakula, Registration No. 40,808, and Robert F.I. Conte, Registration No. 20,354, to

prosecute this application and to transact all business in the Patent and Trademark Office connected herewith. It is requested that all communications be directed to Lee, Mann, Smith, McWilliams, Sweeney & Ohlson, P.O. Box 2786, Chicago, Illinois 60690-2786, telephone number (312) 368-1300.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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